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DESIGN OF LARGE COAL BUNKERS

By Paul Rogers, M. ASCE

STRUCTURAL DIVISION

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PAPERS

DESIGN OF LARGE COAL BUNKERS

By Paul Rogers,[1] M. ASCE

Synopsis

Although coal bunkers of large capacity form an important part of power stations and similar plants, the technical literature contains little information concerning their practical design.

An attempt is made in this paper to present a rational design procedure based upon several coal bunkers actually constructed. Formulas for coal pressures on vertical and inclined walls are reviewed, and values are tabulated; bunker walls are presented as flexible plates; unbalanced forces due to asymmetry are analyzed; and continuity for the stiffeners is introduced.

Introduction

The coal bunkers of modern power stations (see Fig.1) have smooth walls with few vertical stiffeners widely spaced. If possible, these stiffeners should be placed on the inside, thus producing a neat outside appearance requiring little maintenance. There is objection to inside stiffeners, however, when the cyclone type of boilers is used, because the stored coal is composed of small particles and has an excessive tendency to arch. The hoppers of the bunkers have steeply sloped walls to insure the steady flow of coal and are reinforced by only one or two sets of horizontal stiffeners. Most bunkers have a 2½-in. or 3-in. gunite lining on the inside.

Coal Pressure

The pressures produced by the coal on the vertical and inclined walls of the bin can be computed by the shallow bin formulas or the deep bin formulas. The shallow bin theory is applicable to smaller bins where the plane of rupture does not intersect the opposite wall. For most large coal bunkers, however, the deep bin (or silo) theory is applicable. Final formulas for both theories are presented and useful tables are included. Fig. 2(*a*) shows the pressure conditions against the vertical walls of the bin.

Note.—Written comments are invited for publication; the last discussion should be submitted by December, 1951.

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The Shallow Bin Theory.—Pressures in a shallow bin can be computed using the Coulomb theory and substituting commonly accepted constants. Pressure calculations will be based on a level coal surface in the bin. This is justified since most bunkers are loaded from one or more tripper conveyors with double

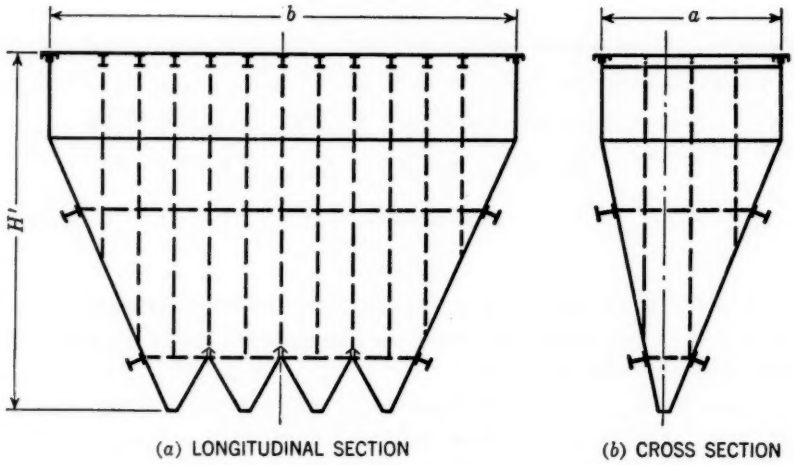

FIG. 1.—TYPICAL COAL BUNKER

spouts. In addition, it is assumed that the coal weight (w) is 50 lb per cu ft and that the angle of repose (ϕ) of the coal is 35°, which equals the angle of friction (ϕ') of the coal against the concrete bin lining.

Pressure Considering Friction.—The equation for total pressure (P) on the bin walls, including friction, is[2]

$$P = [\tfrac{1}{2} w h^2] \left[\frac{\cos \phi}{(1 + \sqrt{2} \sin \phi)^2} \right] \ldots\ldots\ldots\ldots\ldots\ldots (1a)$$

in which h is the depth from the top of the coal load to the point at which pressure is to be calculated. In this form Eq. 1a represents liquid pressure modified by a factor of effectiveness of the coal.

Substituting the assumed values in Eq. 1a:

$$P = 0.25 \times 25\, h^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1b)$$

The force (N) normal to the bin wall can be found by simple trigonometry to be

$$N = 0.205 \times 25\, h^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Pressure Not Considering Friction.—If friction is disregarded, the formula becomes[3]

$$N = P = (\tfrac{1}{2} w h^2) \left(\frac{1 - \sin \phi}{1 + \sin \phi} \right) \ldots\ldots\ldots\ldots\ldots\ldots (3a)$$

[2] "Structural Engineers' Handbook," by Milo S. Ketchum, McGraw-Hill Book Co., Inc., New York, N. Y., 1918, p. 230.

[3] *Ibid.*, p. 229.

Substituting the assumed constants

$$N = 0.27 \times 25\, h^2 \quad \ldots\ldots (3b)$$

Computation of the unit normal pressure (p_n) can be simplified by use of the factors found in Eq. 1*b* and Eq. 3*b* for considering friction

$$p_n = 0.205 \times w\, h \quad \ldots\ldots (4a)$$

or

$$p_n = 10.3\, h \quad \ldots\ldots (4b)$$

If friction is disregarded

$$p_n = 13.5\, h \quad \ldots\ldots (4c)$$

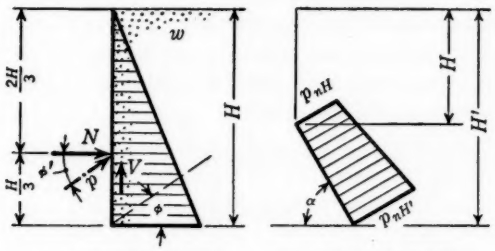

FIG. 2.—PRESSURE DIAGRAMS FOR THE SIDES OF A COAL BUNKER

Consequently, in order to obtain the horizontal pressure in pounds per square foot at a depth h below the top of the coal, multiply p_n by h. For example if $h = 14$ ft, and if friction is considered, the normal pressure at $h = 14$ ft is equal to $10.3 \times 14 = 144.2$ lb per sq ft.

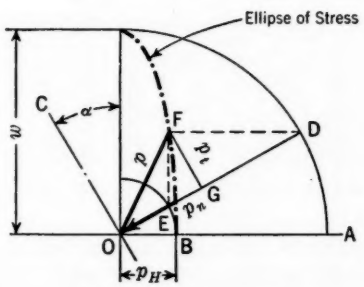

FIG. 3.—GRAPHICAL DETERMINATION OF COAL PRESSURES IN A SHALLOW BIN

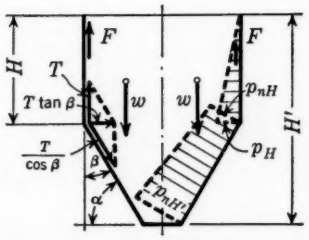

FIG. 4.—PRESSURES AND FORCES IN A SHALLOW COAL BUNKER

Coal Pressure on Inclined Walls.—Fig. 2(*b*) shows the pressure conditions on the inclined walls of a bin. The normal coal pressure on inclined walls can be computed most conveniently by use of the ellipse of stress. Theoretical derivation of the ellipse of stress can be found in standard texts,[4] but Fig. 3 indicates a

[4] "Design of Walls, Bins and Grain Elevators," by Milo S. Ketchum, *Engineering News*, New York, N. Y., 2d Ed., 1911, p. 8.

direct application to coal bins. This diagram is constructed graphically by the selection of suitable scales for the linear quantities and following the procedure outlined:

1. With point 0 as a center, draw two quarter circles. Radius 0A represents the weight of 1 cu ft of coal (50 lb) and radius OB denotes the frictionless horizontal pressure of the coal per foot of depth (13.5 lb). It is customary to neglect friction on inclined walls of shallow bunkers because of exposure to impact during loading.

2. Draw line OC parallel to the inclined wall and line OD perpendicular to it. Angle α is the inclination of the bin wall from the vertical.

3. The coordinates of point F on the ellipse of stress are determined by drawing a horizontal line DF and a vertical line EF from the intersection of line OD with the inner and outer circles, respectively.

4. Line FO now represents the actual pressure p on the inclined wall due to a 1-ft depth of coal. The normal component of $P(p_n)$ is line OG and the tangential component (p_t) is line FG.

Pressures p_n and p_t can also be expressed in the algebraical form

$$p_n = 50 \cos^2 \alpha + 13.5 \sin^2 \alpha \quad \ldots\ldots (5)$$

and

$$p_t = (50 - 13.5) \sin \alpha \cos \alpha \quad \ldots\ldots (6)$$

Table 1 lists values of p_n for frequently used angles. Ordinarily there is no need to compute p_t as this force produces tension in the inclined walls, and this tension can be calculated easily and directly. Fig. 4 indicates the derivation of

TABLE 1.—Coal Pressures p_n (in Pounds Per Foot of Depth) Normal to Walls Inclined at Various Angles α

α	p_n	α	p_n	α	p_n	α	p_n	α	p_n	α	p_n
45	31.8	51	28.0	57	24.3	63	21.0	69	18.2	75	16.0
46	31.1	52	27.3	58	23.8	64	20.5	70	17.8	76	15.6
47	30.5	53	26.7	59	23.2	65	20.1	71	17.4	77	15.4
48	29.8	54	26.1	60	22.6	66	19.6	72	17.0	78	15.1
49	29.2	55	25.6	61	22.1	67	19.1	73	16.7	79	14.8
50	28.6	56	25.0	62	21.6	68	18.6	74	16.3	80	14.6

this tension force. Let W equal the weight of coal supported by the bottom and inclined wall, plus dead load; F equal the portion of coal carried by the wall through friction; and T equal the net vertical load at bend-line ($W - F$). The fraction $\frac{T}{\cos \beta}$ is then the component of T parallel to the inclined wall, or the actual maximum tension in the inclined wall, where β is the angle of inclination of the bin from the vertical. A more complete analysis of these forces will be found in the subsequent section on design of stiffeners.

The Deep Bin Theory.—The pressures exerted by the coal on the vertical walls of a deep bin can be conveniently computed by the use of the Janssen

formula. A readily usable form of this equation[5] for circular bins is:

$$p_h = \frac{w\,R}{\mu'}\,(1 - e^{-k\mu' j}) \qquad (7)$$

in which (to simplify typography): $j = h/R$. In Eq. 7, furthermore: R is the hydraulic radius, A/U; A is the area enclosed by a horizontal section through the bin; U is the perimeter of the same section; μ' is the tangent of the angle of friction, ϕ'; p_h is the unit horizontal pressure; e is the base of Naperian logarithms; and k is the ratio of horizontal pressure, p_h/p_v. The ratio k is approximately equal to $\frac{1 - \sin\phi}{1 + \sin\phi'}$, although the actual value can only be obtained experimentally. Experiments have shown that the ratio of horizontal to vertical pressure varies with the depth and shape of the bin. For practical purposes, however, a constant value will be assumed.

To present Eq.7 in a convenient form for designers, it is assumed that $\phi' = 35°$ on concrete lining and $\phi' = 20°$ on steel plate; and $\mu' = 0.70$ on concrete and $\mu' = 0.37$ on steel. Angle ϕ equals 35°. Substituting assumed values the formula for horizontal pressure of coal on concrete bin walls is:

$$p_h = 71.5R\,(1 - e^{-0.189j}) \qquad (8a)$$

The corresponding formula for coal pressure on steel plate is

$$p_h = 135\,R\,(1 - e^{-0.100j}) \qquad (8b)$$

Pressures p_h and p_v are functions of R and h. The quantity $1 - e^{-k\mu' j}$ is a function of h/R. Table 2 gives values of this quantity in Eq. 8a for a large variety of ratios h/R. Table 3 gives the actual values (pounds per square foot) of coal pressure for a variety of values of hydraulic radius R.

TABLE 2.—VALUES OF $1 - e^{-0.189j}$ FOR USE IN EQUATION 8a

h/R (1)	$1-e^{-0.189j}$ (2)	h/R (1)	$1-e^{-0.189j}$ (2)	h/R (1)	$1-e^{-0.189j}$ (2)	h/R (1)	$1-e^{-0.189j}$ (2)	h/R (1)	$1-e^{-0.189j}$ (2)
0.3	0.058	1.4	0.237	3.0	0.435	5.5	0.646	11.0	0.877
0.4	0.068	1.5	0.244	3.2	0.451	6.0	0.680	11.5	0.888
0.5	0.086	1.6	0.259	3.4	0.473	6.5	0.708	12.0	0.897
0.6	0.104	1.7	0.274	3.6	0.493	7.0	0.733	12.5	0.906
0.7	0.122	1.8	0.288	3.8	0.512	7.5	0.758	13.0	0.915
0.8	0.139	1.9	0.302	4.0	0.528	8.0	0.779	13.5	0.922
0.9	0.156	2.0	0.316	4.2	0.546	8.5	0.800	14.0	0.928
1.0	0.173	2.2	0.343	4.4	0.564	9.0	0.817	14.5	0.936
1.1	0.190	2.4	0.362	4.6	0.581	9.5	0.835	15.0	0.941
1.2	0.205	2.6	0.387	4.8	0.597	10.0	0.849	16.0	0.950
1.3	0.221	2.8	0.411	5.0	0.609	10.5	0.862	17.0	....

The pressures computed by Eqs. 7 and 8 apply only to cylindrical cross-sections, and the pressure values must be multiplied by a coefficient in order to be applicable to square and rectangular cross sections. The hydraulic radius R is the same for a square as for its inscribed circle. The area of the square is

[5] "Reinforced Concrete Water Towers, Bunkers, Silos, and Gantries," by W. S. Gray, *Concrete Publications, Ltd.*, London, England, 2d Ed., 1944, p. 111.

27% greater, however, than that of the inscribed circle, which means that a square bin carries a 27% larger volume of coal than a circular one. Consequently, the values of p_h and p_v should be computed for the hydraulic radius R of the equivalent circle, the diameter of which is 13% larger than the side of the square. Thus the equivalent hydraulic radius (R') for a square bin is 1.13 ($a/4$).

The pressures on the walls of a rectangular bin in the short direction (a) can

TABLE 3.—HORIZONTAL PRESSURES p_h (IN

$R = A/U$	DEPTH h, IN FEET											
	5	10	15	20	25	30	35	40	45	50	55	60
	(a) Coal on Concrete Lining											
3.0	60	100	130	155	170	180	190	200	200	205	210	210
3.5	60	105	140	165	185	200	210	220	230	235	240	240
4.0	60	110	145	175	200	215	230	245	250	260	265	270
4.5	60	110	150	185	210	230	250	265	275	280	290	295
5.0	60	115	155	190	220	240	260	280	290	305	315	320
5.5	60	115	160	195	230	250	275	295	310	325	335	340
6.0	65	120	165	200	235	265	290	310	325	340	350	365
6.5	65	120	165	205	240	270	300	325	340	360	370	385
7.0	65	120	165	210	245	280	310	335	350	370	390	400
7.5	65	120	170	215	250	285	315	340	365	385	400	420
8.0	65	120	170	215	255	290	320	350	375	400	415	435
8.5	65	120	175	220	260	295	330	360	385	410	430	450
9.0	65	120	175	220	265	300	335	370	395	420	440	460
9.5	65	120	175	225	270	305	340	370	400	430	450	475
10.0	65	120	180	225	270	310	345	380	410	440	460	490
10.5	65	120	180	230	270	315	350	390	420	450	470	500
11.0	65	120	180	230	275	320	355	390	425	455	480	505
11.5	65	120	180	230	275	320	360	400	430	460	490	515
12.0	65	120	180	235	280	325	365	400	435	465	500	530

be computed as for a square bin with sides a, but in the long direction(b) the pressures are larger and must be computed on the basis of an equivalent square bin with sides of $a' = \frac{2ab - a^2}{b}$. Setting b equal to $m\,a$, in which m is a coefficient always larger than unity, a' can be expressed as $= a\left(2 - \frac{1}{m}\right)$, or $a' = z\,a$.

These values can be easily tabulated:

m	z	m	z
1.00	1.00	2.25	1.56
1.25	1.20	2.50	1.60
1.50	1.33	2.75	1.64
1.75	1.43	3.00	1.67
2.00	1.50		

Coal Pressures on the Inclined Walls of Deep Bins.—The pressures on the inclined walls of deep bins can be computed easily by use of the ellipse of stress.

According to the Janssen theory, the horizontal pressure p_h is equal to k times the vertical pressure p_v; thus:

$$p_h = k\, p_v \quad \ldots\ldots (9a)$$

The ratio k has been determined previously and is equal to 0.27. Substituting this value in Eq. 9*a*, p_v is found in terms of p_h:

$$p_v = 3.7\, p_h \quad \ldots\ldots (9b)$$

POUNDS PER SQUARE FOOT) BY EQUATION 8*a*

DEPTH *h*, IN FEET												$R = A/U$
5	10	15	20	25	30	35	40	45	50	55	60	
(*b*) Coal on Steel Plates												
65	115	160	200	230	255	280	300	315	330	340	350	3.0
65	120	165	205	240	270	300	320	340	360	375	390	3.5
65	120	170	210	250	285	315	340	365	385	400	420	4.0
65	120	170	220	260	295	330	360	385	405	425	445	4.5
65	120	175	225	265	305	340	370	400	425	450	470	5.0
65	125	175	225	270	310	350	385	415	445	470	495	5.5
65	125	180	230	275	320	355	395	430	460	485	510	6.0
65	125	180	235	280	325	365	405	440	470	505	530	6.5
65	125	185	235	285	330	370	410	450	480	515	545	7.0
65	125	185	240	285	335	375	420	455	490	525	555	7.5
65	125	185	240	290	340	385	425	465	500	540	570	8.0
65	125	185	240	295	340	390	430	470	510	550	585	8.5
65	125	190	240	295	340	390	435	480	515	555	595	9.0
65	130	190	245	295	350	395	440	485	525	565	600	9.5
65	130	190	245	300	350	400	445	490	530	570	610	10.0
65	130	190	245	300	350	400	445	495	535	575	615	10.5
65	130	190	245	300	350	405	450	500	540	580	620	11.0
65	130	190	250	300	355	405	450	500	545	590	630	11.5
65	130	190	250	305	360	410	460	510	555	600	635	12.0

A graphical solution for the bin pressures provides the most convenient approach to the problem. This procedure is outlined here, with reference to Fig. 5.

a. Plot a cross section of the bin to any convenient scale. Alongside the bin erect line AC and subdivide this line into 5-ft scale intervals, starting at the top. Extend the subdivision lines through the bin and compute the hydraulic radius at each 5-ft interval.

b. By computation (or by Table 3), determine the horizontal pressure (p_h) at each level. These pressures are plotted to a convenient scale perpendicular to line AC (line BD, for example). The horizontal pressure diagram (line ADC) is determined by connecting successive values of p_h.

c. The pressure on the inclined walls is determined by constructing an ellipse of stress as described previously. If radius OA of Fig. 3 is drawn to a value of 3.7, representing p_v, and line OB is made equal to a value of 1.0 at the same scale, representing p_h, then a coefficient value for p_n can be obtained for the given slope of bin wall. The horizontal pressures at each 5-ft level in Fig. 5 are multiplied by this coefficient to obtain the absolute value of p_n.

d. The total normal pressure on the inclined wall is obtained by adding the normal component of the dead load of the bunker plate and lining to the pressure due to the coal.

Table 4 gives values of p_n based on $p_h = 1$ and $p_v = 3.7$ for a number of common wall slopes. To obtain transverse loading on stiffeners, multiply the total normal pressure by the stiffener spacing. This loading produces bending in the stiffeners.

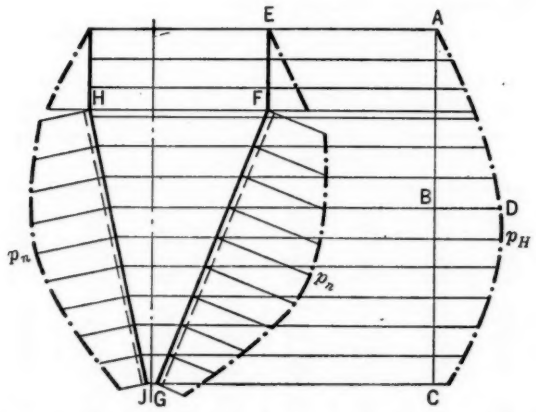

FIG. 5.—GRAPHICAL DETERMINATION OF COAL PRESSURES IN A DEEP BIN

A standard form for use in tabulating pressures is a useful analytical tool. The suggested table contains eight columns and is simple yet complete. The columns to be used are:

Column No.	Caption
1	Depth.—The location of the point of analysis below the top of the bin.
2	Bin Ratio.—The ratio of length to width of the bin (b/a).
3	z Values.—Determined from listing in previous section.
4	Hydraulic Radius in Short Direction.—This equals 1.13 $a/4$ as previously explained.
5	Hydraulic Radius in Long Direction.—Equals z times the value from Col. 4.
6	Correction for Inclination of Walls.—Determined from Table 4.
7	Normal pressure in the short direction.
8	Normal pressure in the long direction.

DESIGN OF FLEXIBLE BUNKER PLATES

The conventional flexural theory is not adaptable to flexible plates that have deflections exceeding half of the plate thickness under normal loading conditions. Flexible plates can carry much heavier loads than ordinary theory would permit because the steel area around the neutral axis is utilized to carry additional loads

through pure tension in addition to the areas near the outside fibers which carry loads by flexural tension and compression.

TABLE 4.—COAL PRESSURE COEFFICIENT p_n TO DETERMINE THE PRESSURE NORMAL TO WALLS INCLINED AT VARIOUS ANGLES α

α	p_n	α	p_n	α	p_n	α	p_n	α	p_n	α	p_n
45	2.36	51	2.07	57	1.80	63	1.56	69	1.35	75	1.18
46	2.31	52	2.02	58	1.76	64	1.52	70	1.32	76	1.16
47	2.26	53	1.98	59	1.72	65	1.49	71	1.29	77	1.14
48	2.21	54	1.93	60	1.68	66	1.45	72	1.26	78	1.12
49	2.17	55	1.89	61	1.64	67	1.42	73	1.24	79	1.10
50	2.12	56	1.85	62	1.60	68	1.38	74	1.21	80	1.08

The analysis of flexible plates is given in many books of advanced strength of materials. The values of allowable loads for plates of different thicknesses and a variety of spans, with both free and clamped edges, are given in Table 5, which is based on formulas and charts presented by S. Timoshenko.[6] The values are calculated for 20,000 lb per sq in. allowable stress.

TABLE 5.—ALLOWABLE LOADS (IN POUNDS PER SQUARE FOOT) ON FLEXIBLE PLATES

PLATE THICKNESS		SPANS, IN FEET								
Inches	End condition	2.0	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0
½	Simply supported	980	890	870	855	840	....	....	....	....
	Fixed	640	310	240	200	180	....	....	....	....
⅝	Simply supported	....	985	940	910	890	880	870	855	835
	Fixed	....	655	560	380	300	260	225	200	165
¾	Simply supported	....	....	1,025	980	930	920	905	890	870
	Fixed	....	....	830	640	420	420	360	310	240
⅞	Simply supported	....	....	....	1,050	1,015	980	950	935	900
	Fixed	....	....	....	940	780	640	530	460	340

Table 5 indicates that, because of the increased resistance to bending, flexible plates (unlike ordinary slabs) carry much less load with the ends fixed than with ends simply supported.

Bunker plates, riveted or welded to stiffeners, are neither fixed nor simply supported, and an intermediate value should be chosen. Ordinarily ⅞-in. plate thickness is sufficient for all practical purposes. Neither the increase of plate thickness nor of the span produces any pronounced variation in the value of the allowable load.

No allowance was made for the gunite lining, due to its possible deterioration and wear, although it is obvious that it adds materially to the load-carrying capacity of the plates.

[6] "Theory of Plates and Shells," by S. Timoshenko, McGraw-Hill Book Co., Inc., New York, N. Y., 1940.

The Analysis of the Intersection of Vertical and Inclined Stiffeners

It was shown in Fig. 4 that there is an inward force acting at the intersection of the vertical and inclined walls equal to $T \tan \beta$.

The coal pressures on the vertical and inclined walls produce outward forces F_h and F_n as shown in Fig. 6(*a*).

The ideal case occurs when the sum of $T \tan \beta$ plus F_n, and the horizontal component of F_n equal zero. This can be accomplished by establishing the location of the horizontal stiffener so as to produce the proper reaction F_n at the intersection. Quite often, however, the location of the horizontal stiffener is set by other requirements, and consequently a resultant inward force is created at the intersection.

This inward force can be resisted by a horizontal member at the intersection or by designing the broken-back vertical stiffeners to resist the bending created by this force.

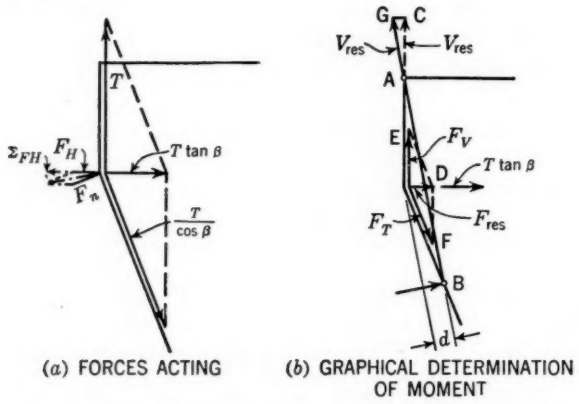

Fig. 6.—Analysis of Intersection of Vertical and Inclined Walls of a Coal Bunker

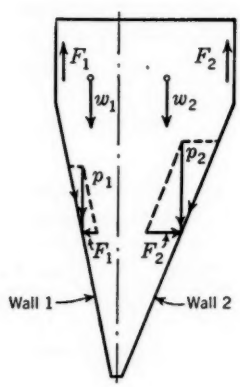

Fig. 7.—Forces in an Asymmetrical Coal Bunker

The maximum moment due to this inward force to be resisted by the vertical stiffener is most conveniently determined by graphical methods. The procedure is outlined here with reference to Fig. 6(*b*):

(1) Graphically, resolve the resultant inward force (F_{res}), represented by line OD into two components, one parallel to the vertical stiffener (OE) and one parallel to the inclined stiffener (OF).

(2) Draw line BA connecting the horizontal stiffener at point B with the horizontal support at point A.

(3) Lay off the force F_v (line OE) above point A (line AC) and determine the force component parallel to the connecting line BA.

(4) The maximum moment is determined by multiplying the parallel component of F_v (line AG) by the perpendicular distance (d) from line BA to point O.

Design the vertical stiffeners to resist the combined effect of this moment, the negative moment due to the coal pressure, and the maximum tension

$T/\cos\beta$. The bunker plate and the stiffeners act as one unit; thus the stiffeners should be designed as T-beams.

Analysis of Unbalanced Forces

In case the inclined walls are of different slopes, the bunker will tend to assume a symmetrical shape. This tendency to overcome asymmetry produces an unbalanced horizontal force. The amount of this horizontal force can be computed as shown on Fig. 7.

Divide the bunker into two parts by means of a vertical line through the bottom opening, and compute the coal weights (W_1 and W_2) and the weight of coal carried by the vertical walls (F_1 and F_2).

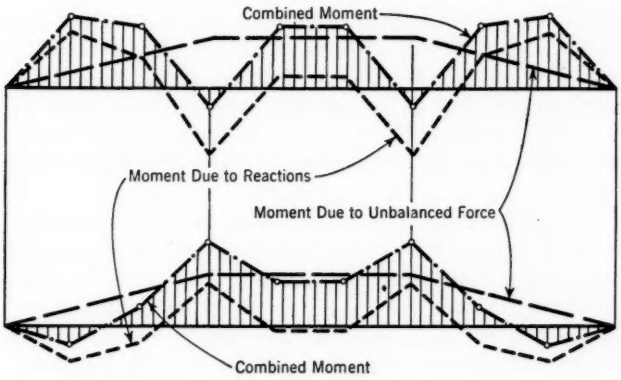

Fig. 8.—Moment Diagram for Horizontal Girder

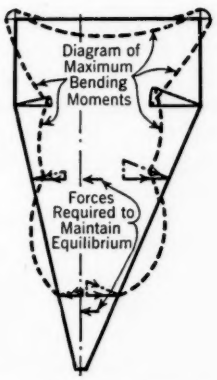

Fig. 9.—Moment Diagram for Design of Vertical Stiffeners

The force on the inclined wall is the sum of the coal weight and dead load minus the weight of coal carried by the vertical wall. If this value is computed for both walls and the horizontal components found, the difference in horizontal components of the two walls is the unbalanced force to be resisted.

This can be accomplished by providing one or more horizontal girders on the inclined walls. These girders will support the reactions of the vertical stiffeners, which automatically include the unbalanced forces. Long bunkers ordinarily have horizontal struts at specific intervals connecting the horizontal girders. These struts have the effect of creating continuous beams out of the horizontal girders.

In the case of asymmetry, however, the reactions of the horizontal girders on the struts are opposite but not equal, and the difference between these reactions creates concentrated loads on the girder that spans between endwalls.

Fig. 8 shows the moment diagram of a typical horizontal girder with two struts. This diagram indicates moments for bending due to the reactions of vertical girders and for the differential reactions of the struts. The two moments then are superimposed in order to obtain the maximum moments.

Design of the Vertical Stiffeners.—The two sets of vertical stiffeners at any cross section should be designed by the use of continuity principles. In this method the upper horizontal girder, which supports the flooring and the coal unloading tripper, should be included.

It may be necessary to make several analyses, for instance with, and without tripper loading, or with the bunkers fully and partly loaded. A simplified analysis for such cases has been presented by the writer.[7]

A typical moment diagram for an asymmetrical bunker is given in Fig. 9. These moments are used in the design of the vertical stiffeners.

Limitations of the Coal Bunker Design

The foregoing theory and analysis of large coal bunkers furnishes practical solutions for safe and economical design. Investigations and field measurements conducted on a large coal bunker indicate that the actual pressures did not vary materially from values computed on the basis of theories expressed in this paper. Extensive studies conducted in France[8] imply that the ratio of horizontal to vertical pressure (k) is not a constant but varies with the depth of the stored material and with the shape of the bin. The filling and emptying of the bin produce different pressures which do not seem to follow any regular pattern.

The actual stresses in the plates and beams are probably much less than the computed values. The effect of the gunite lining on the plates, the composite T-beam action of the beams, the probable diaphragm action of the walls, and the stress-reduction effect of the tangential forces in the plates as expressed by Poisson's ratio all characterize a complex structure in which all members act simultaneously, thus greatly reducing the stresses in the individual members. Actual strain-gage measurements on a large bunker suggested the presence of extremely low stresses in the bunker plates.

The use of the foregoing analysis, with the exception of formulas for coal pressures, is not recommended for the design of reinforced concrete bunkers. Concrete bunkers with rigid plates and no stiffeners for walls are most conveniently designed as hipped plate construction.[9]

Summary

Design formulas for the practical analysis of large-capacity coal bunkers have been presented. Several figures and tables are included in order to facilitate analysis and to reduce computations to the minimum. It is believed that this paper will be a useful tool for the office designer.

[7] "Simplified Analysis for Live Loads," by Paul Rogers, *American Concrete Institute Journal*, Vol. 20, October, 1949, p. 144.

[8] "Recherches nouvelles sur les efforts exercés par les matièrs pulvérulentes ensilées sur les parios des silos," by M. Reimbert, Institut Technique du Batiment et des Travaux Publics, Paris, France, May 10, 1943.

[9] "Hipped Plate Construction," by George Winter and Minglung Pei, *American Concrete Institute Journal*, Vol. 18, January, 1947, p. 505.

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